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Identification of Lightweight Concrete Characteristics Based on Density, Compressive Strength, and Absorbency Values with the Addition of Fly Ash and Glass Waste Aggregates

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Abstract

Fly ash and glass waste can pose a significant environmental problem, as they cannot naturally decompose in the environment. This occurs due to the presence of pozzolan and silica in the waste. The purpose of this study is to categorize lightweight concrete and evaluate its properties, including density, compressive strength, and water absorption when incorporating additional fly ash and glass waste. This research uses experimental methods in the laboratory with a total of 72 samples with dimensions (25x25x50) mm in the form of blocks. Concrete samples were divided into two variations of storage duration, namely 21 days and 28 days, and given the same treatment and testing. The fly ash mixture variations used in this study were 0%, 20%, 40%, and 60%, with each variation consisting of 3 samples. The results obtained in this study indicate that, when viewed in terms of age, concrete with a storage period of 28 days exhibits better quality than 21-day-old concrete. Based on the density value, both 21-day-old and 28-day-old concrete samples fall within the quality category of lightweight concrete, as per category A. When viewed from the compressive strength value, 21-day-old and 28-day-old concrete are of C quality. Regarding water absorption, the best value is achieved by the concrete mix with a 20% fly ash content and an 11% water absorption rate. When compared with concrete samples that do not contain fly ash, it is known that the test results on concrete samples without fly ash (0%) have higher compressive strength and density values, and the percentage of water absorption is by SNI standards.

INTRODUCTION

Material engineering in the modern era has led to an increase in the material processing industry, primarily for building purposes and alternative materials industries. One of the growing industries in the construction field is the concrete industry [1]. Concrete is a fundamental component of building construction, comprising basic ingredients such as cement, fine aggregate, and coarse aggregate. Concrete has several classifications based on the types of constituent materials, functions, physical properties, and mechanical properties. Physical properties include density, porosity, moisture content, and water absorption ability. In general, concrete can be categorized into conventional concrete, lightweight concrete, and high-performance concrete. The use of lightweight concrete is intended to reduce the structural load [2]. In general, lightweight concrete is used in building walls or as a guardrail in everyday life.

Lightweight concrete, based on the standard reference [3], can be divided into four groups based on compressive strength, wear resistance, and water absorption: (1) Class A, with a compressive strength of approximately 40 MPa, wear resistance of 0.090 mm/mi, and a maximum water absorption of 3%. (2) Class B with a compressive strength of about 20 MPa, wear resistance of 0.130 mm/min, and maximum water absorption of 6%. (3) Class C with a compressive strength of about 15 MPa, wear resistance of 0.160 mm/min and maximum water absorption of 8%, and (4) Class D with a compressive strength value of about 10 MPa, wear resistance of 0.219 mm/min and maximum water absorption of 10%. According to research [4], lightweight concrete can be divided into 3 groups based on density and compressive strength: (1) Class A lightweight concrete or structural lightweight concrete with a density of 1,400 kg/m^3 - 1,850 kg/m^3 with a compressive strength of 17 MPa - 41 MPa, which is used as regular concrete. (2) Class B lightweight concrete or structural lightweight concrete is a *moderate strength concrete* with a density of 800 kg/m³m^3 m³ to 1,400 kg/m^3 m³ and a compressive strength of 7 MPa to 17 MPa. This lightweight concrete is not used to carry structural loads; it is typically used in building walls. (3) *Insulating* concrete or class C lightweight concrete (*Insulating Concrete*). Insulating lightweight concrete or non-structural lightweight concrete is lightweight concrete with a density of 240 kg/m³ - 800 kg/m³ and a compressive strength of 0.35 MPa - 7 MPa, which is used as heat-retaining concrete (heat insulation) or referred to as *low-density concrete*, where this concrete does not use additional ingredients.

Generally, structural lightweight concrete weighs 20%-40% less than conventional concrete, which reduces the dead load of the structure, lowers construction costs, and reduces the amount of reinforcement required. The materials used in traditional concrete manufacturing come from non-renewable natural resources, such as sand and cement. The manufacturing process of these materials, including cement, is one of the causes of global warming through greenhouse gas emissions. Concrete road construction using the fuel conversion method results in greenhouse gas emissions of 1,224,876.384 kg CO2, with a breakdown of 85.38% at the production stage, 14.41% at the transport stage, and 0.21% at the construction stage [5]. Another factor contributing to global warming is the burning of coal in Steam Power Plants (PLTU), which generates *fly ash* waste.

Fly ash is a residual material or waste derived from burning coal at a power plant with a combustion temperature of 1,250°C to 1,600°C. Significantly, *fly ash* has a silica component of 67.20% and alumina of 23.89% (Debnath, 2021), which consists of oxide mineral compounds such as silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), titanium oxide (TiO_2), sodium oxide (Na_2O), magnesium oxide (MgO), and potassium oxide (K_2O). *Fly ash* is classified as waste that is harmful to humans if not properly managed, with a cumulative amount of fly ash and bottom ash found in PLTUs throughout Indonesia ranging from 5.8 to 9.7 million tonnes [6]. *Fly ash* can be used as a substitute for cement in the manufacture of lightweight concrete. Concrete also requires aggregate as reinforcement in the manufacturing process; this aggregate can be used in fine or coarse form. One of the aggregates used in the manufacture of concrete is sand, which has a high silica content and serves as a filler in concrete. The sand used in the manufacture of concrete is obtained through sand mining, which can harm the environment by altering the geography of an area and causing erosion around rivers, as well as changes in river depth. This will have an impact on the surrounding ecosystem, including humans, flora, and fauna, particularly in terms of the decline in water quality and the deterioration of community irrigation systems [7]. Sand material has alternative substitutes such as glass waste, this is because glass waste has a mineral content similar to sand [8]. Glass waste can be a hazardous waste for the environment because this waste takes up to 1,000,000 years to decompose and can become soil pollution if not appropriately managed Therefore, *fly ash* waste and glass waste are expected to be used as a substitute for cement and sand in the manufacture of lightweight concrete.

The utilisation of fly ash as a fine aggregate in the manufacture of concrete has been carried out by [10]. In this study, the quality of concrete was evaluated through compressive tests, tensile tests, absorption tests, and density tests. The highest compressive test obtained in this study was 36.9 N/mm^2 . Lightweight concrete in a mixture of 50% fly ash and 50% *Bottom Ash* as a sand substitute with a concrete age of 90 days. The highest absorption test was conducted on a mixture of 50% fly ash and 50% *Bottom Ash, with a value of 6.85% at* 90 days. Concrete with 0% fly ash and *Bottom Ash* variation had the highest density value of 2,373.38 kg/m^3 m³. Another study was conducted by [11] using glass waste as a filler material in the manufacture of concrete. The results obtained in this study were the highest compressive test value of 36.256 kg/cm^2 in the 10% mixture. The result of the water absorption test with a 10% mixture is 4.92%. The density test results for concrete bricks with the optimal glass powder addition were obtained at a 5% glass powder addition, yielding a density value of 1956 kg/m³. In addition, similar research was conducted by [12] using glass waste and fly ash as substitutes for concrete materials. The results obtained in this study are the highest tensile test and absorption test values, at 2.943 MPa and 18.5%, respectively.

Based on the description presented, the purpose of this study is to determine the effect of *fly ash* mixture on the manufacture of lightweight concrete and to determine the category of lightweight concrete produced when viewed based on density, compressive strength, and water absorption values. The standards for compressive strength and absorption were established in 1996 using SNI 03-0691, and the standard for density value was based on Mulyono's research.

RESEARCH METHODS

This research was conducted at the Physics Laboratory of FMIPA, Mataram University, using the experimental method. The study involved collecting materials, mixing them, creating test objects, testing the mechanical properties of these objects, and analyzing the results. The sample used in this study has dimensions of 25 mm x 25 mm x 50 mm. *Fly ash* is used to replace a varying percentage of cement, ranging from 0% to 60% by weight of the cement. The waste glass in the form of coarse aggregate was used as a substitute for sand at 20% of the weight of sand. The amount of waste glass used was constant for each sample composition.

Material

The materials used in this study were PCC cement with a compressive strength value / 28 days using the standard [13] sebesar ≥ 280 kg/cm², dug sand from the Ijo Balit area, Glass Waste aggregate obtained through a building deconstruction site, and *fly ash* obtained from the Jeranjang PLTU in West Lombok Regency. The preparation of the materials used included sieving the cement to reduce the clumping effect of the material. Sand was also sieved using a 100-mesh sieve to obtain sand with a smaller size. The glass waste, received in the form of broken glass, was then crushed with a mortar and sieved using a 50-mesh sieve.

Manufacture of Lightweight Concrete

The manufacture of concrete begins with preparing the materials used (*fly ash*, water, sifted glass waste, filtered sand, and cement). Then, each material is weighed using a digital balance. After the material weighing process, the ingredients are mixed in a single container and stirred for 5 minutes until they are evenly distributed. After stirring, the ingredients are mixed with water, then put in a mould and vibrated using a vibrator to reduce pores in the concrete. The concrete was placed indoors for 12 hours, and after this period, it was removed from the mold and dried indoors for 21 to 28 days. The concretes were made using the standard structural rigid concrete manufacturing in [14]. The composition of the ingredients used as admixtures is shown in Table 1.

Table 1. Composition of *Fly Ash* and Glass Blended Lightweight Concrete Samples

Sample Code	Mix Composition				Number of Test Objects
	Cement	Pasir	Cement	Limbah Kaca	
$B_{0\%}$	21 gr	33,6 gr	0	8,4 gr	18
$B_{20\%}$	16,8 gr	33,6 gr	4,2 gr	8,4 gr	18
$B_{40\%}$	12,6 gr	33,6 gr	8,4 gr	8,4 gr	18
$B_{60\%}$	8,4 gr	33,6 gr	12,6 gr	8,4 gr	18

The water composition used in the manufacture of concrete samples has a *w/c* ratio of 0.70. This value is categorised as relatively high, and this occurs because the use of *fly ash* tends to cause the mixture to be dry and easily broken. The number of concrete samples produced was 72, with 24 samples designated for the density test, compressive strength test, and water absorption test. The data in Table 1 indicate that there are 18 test samples for each type, as three repetitions are carried out for each test. In addition, two variations of sample treatments were carried out, namely 21 days and 28 days, so that 18 concrete samples were required for each category.

Sample Test

Quality testing of concrete samples is applied to all samples produced. Concrete samples were tested using the density test, the compressive strength test, and the absorbency test. Density measurement begins with putting concrete into a measuring cup, determining the difference in water level, and measuring the diameter of the measuring cup using a caliper. The concrete was then dried for 1 hour in an oven at 105 ºC. The dry mass and wet mass of the concrete (soaked for 1 hour) were weighed using an analytical balance. The compressive strength test was carried out on concrete samples that had undergone a treatment period of 21 and 28 days, measured using a hallway to determine the value of A (cross-sectional area). The concrete was placed on a compressive tester (Tensilon), and then it was pressed until it broke to determine the value of F (maximum load) of the concrete. The density test in this study utilized the equation [15].

$$\rho_b = \frac{m_b}{V_t} \times 1.000 \quad (1)$$

Compressive strength is the amount of load that can be received by concrete per unit area [16]. The compressive strength test was carried out based on [17] using the Tensilon RTG-1310 tool, a Japanese brand with a maximum compressive force of 10kN, and the compressive strength value was calculated using equation (2):

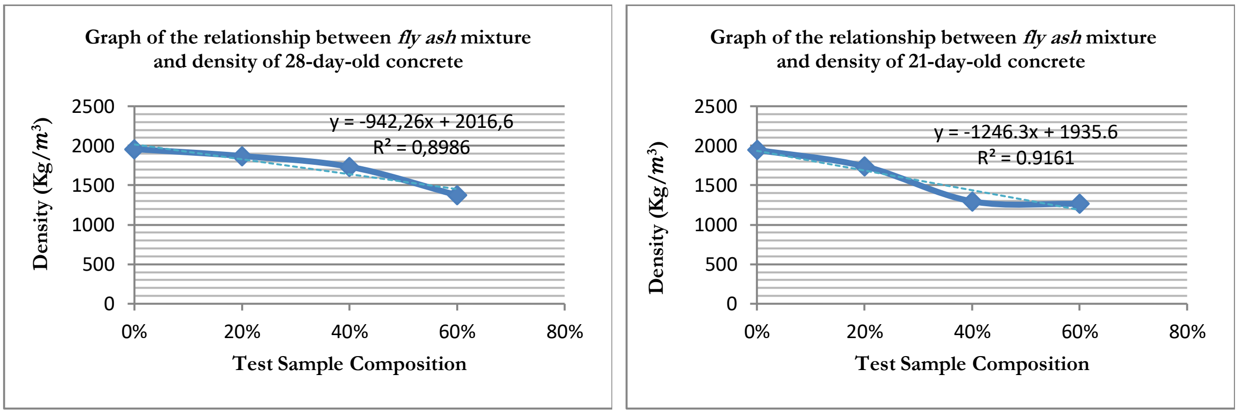
$$P = \frac{F}{A} \quad (2)$$

Water absorption is the ability of concrete to absorb water; the purpose of this test is to determine the quality of concrete as a construction material [18]. Concrete absorption testing begins with drying the concrete in an oven at 24°C for 24 hours. The mass of the concrete is weighed using an analytical balance. Then, the concrete is cooled in the room and soaked in water for 24 hours. After that, the concrete was soaked and weighed to obtain the wet mass. The absorption equation is based on [19] with equation (3):

$$Absorption\ capacity = \frac{w_2 - w_1}{w_1} \times 100\% \quad (3)$$

RESULTS AND DISCUSSION

The results of testing concrete samples were obtained for the values of density, compressive strength, and water absorption of concrete aged 21 days and 28 days. The glass waste aggregate in this study was determined to be a constant value of 8.4 g, while the addition of *fly ash* was 4.2 g (20%), 8.4 g (40%), and 12.6 g (60%). The addition of *fly ash* is best in the mixture with 20% *fly ash*. When reviewed based on the length of storage time, 28-day-old concrete samples have better quality when compared to 21-day-old concrete samples. Figure 1 shows the graph of density test results.



(a) (b)

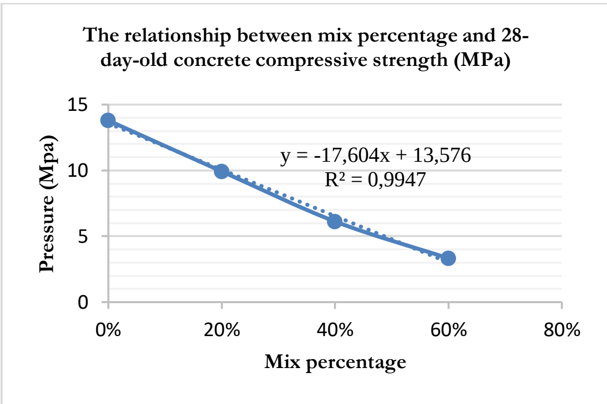
Figure 1. Density of concrete samples: (a) 28 days old and (b) 21 days old

Based on Figure 1, the density of 28- and 21-day-old concrete samples decreased as the percentage of *fly ash* increased. The densities of 28-day-old concrete samples with 0%, 20%, 40%, and

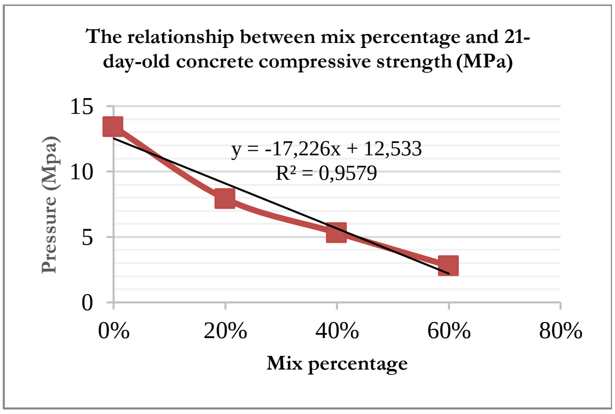
60% fly ash blends are 1,957.32 kg/m^3; m³, 1869.87 kg/ m³, 1,733.98 kg/ m³, and 1,374.42 kg/ m³. The concrete sample with a 0% fly ash mix percentage has the highest density, and the lightweight concrete with a 60% *fly ash* mix percentage has the lowest density. The same was true for the 21-day-old concrete samples. The density values were 1,947.07 kg/m^3 , 1,739.37 kg/m^3 , 1,296.63 kg/m^3, and 1,263.76 kg/m^3 , respectively.

The results obtained in this study indicate a decrease in density value as the percentage of fly ash increases. However, on the other hand, the density of lightweight concrete increases with an extended curing period. This occurs because the density of *fly ash* is lower than that of cement, so that the aggregates in lightweight concrete with a higher percentage of fly ash mixture reduce the bond between aggregates and, consequently, the density of the concrete. The decrease in density value in this study aligns with the research conducted by [20]. The density of *fly ash* is lower than that of cement, so aggregates in lightweight concrete with a higher percentage of fly ash admixture reduce the bond between aggregates and consequently decrease the density of the concrete. Based on the research [21], the quality of the lightweight concrete, as determined by the density obtained in this study, falls within the classifications of lightweight concrete classes A and B. The class of lightweight concrete obtained through the density test does not match the class of lightweight concrete based on compressive strength, as the density and compressive strength of lightweight concrete are correlated as described by [22].

Tests of compressive strength values are shown in Figure 2, with Figure 2(a) representing the compressive strength values of 28-day-old concrete samples, and Figure 2(b) representing the compressive strength values of 21-day-old concrete samples.



(a)



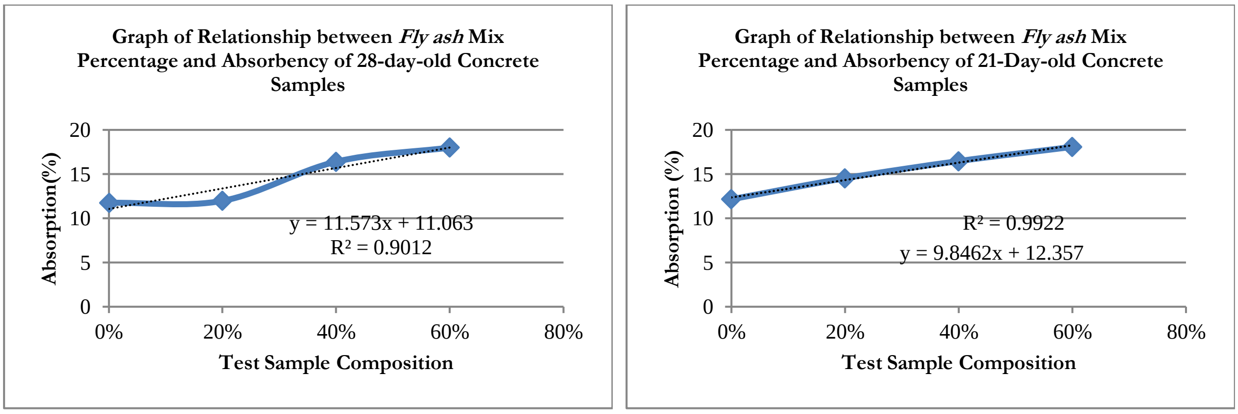
(b)

Figure 2. Compressive strength of concrete samples: (a) 28 days old and (b) 21 days old

Similar to the density values, the compressive strength values of the 21 and 28-day-old concrete samples decreased as the percentage of *fly ash* mixture increased. The 28-day aged lightweight concrete with 0%, 20%, 40%, and 60% *fly ash* admixture percentage had values of 13.796 MPa, 9.920 MPa, 6.126 MPa, and 3.328 MPa, with the lowest value obtained in concrete with 60% *fly ash* admixture and the highest compressive strength obtained in concrete with 0% *fly* ash admixture percentage. Similarly, the 21-day-old concrete samples had average compressive strength values of 13.498 MPa, 7.922 MPa, 5.322 MPa, and 2.801 MPa, respectively, corresponding to fly ash contents of 0%, 20%, 40%, and 60%. The compressive strength value of 28-day-old concrete is greater than that of 21-day-old lightweight concrete. The compressive strength values were also lower compared to the samples without fly ash because the w/c ratio of the concrete samples was 0.70. Ideally, the *w/c* ratio should be below 0.40 for lightweight concrete. However, when a *w/c* ratio of 0.40 is made, the sample cracks easily due to the presence of *fly ash* in the mixture.

Figure 3 shows that the absorbency value of 21 and 28-day-old lightweight concrete increases as the percentage of *fly ash* mixture increases. The 28-day-old lightweight concrete has values of 11.76% for a 0% mix percentage, 11.98% for a 20% mix percentage, 16.41% for a 40% mix percentage, and 17.80% for a 60% mix percentage. The highest absorption value was obtained for the 60% mix, and the lowest value for the 0% mix. The 21-day-old lightweight concrete had values of

12.157% for a 0% mix percentage, 14.54% for a 20% mix percentage, 16.48% for a 40% mix percentage, and 18.08% for a 60% mix percentage. The absorbency value of 21-day-old lightweight concrete with 0% to 60% *fly ash* percentage is greater than the value of 28-day-old lightweight concrete.



(a) (b)

Figure 3. Absorbency of Concrete Samples: (a) 28-day-old concrete and (b) 21-day-old concrete

The absorption value obtained in this study shows that the absorption value of lightweight concrete increases as the percentage of *fly ash* mixture increases. This is because the density of fly ash is lower than that of cement, and its absorption capacity is higher than that of cement. The absorption value obtained is still lower than that reported in research conducted by [23], with an absorption value of 28.5-29.61%. The absorption value obtained is < 35%, so these CLC bricks can be categorised as type 2 solid concrete bricks. Lightweight concrete with a high percentage of *fly ash* has high absorption. This is due to the decreased bond between aggregates resulting from the smaller amount of cement compared to fly ash, which affects the voids contained in the concrete when soaked, thereby reducing the compressive strength and density of the lightweight concrete. On the one hand, glass waste can be used as a supplementary material to reduce the absorption of *fly ash,* which is higher than that of cement. The results of this study are based on research [12], which found that using glass waste as an aggregate has a positive effect on reducing the absorption rate of concrete. The results showed that concrete with a mixture of 20% glass and 20% *fly ash* had the lowest absorption value compared to concrete with a mixture of 20% *fly ash* and 0% glass waste. This is due to the impermeable nature of the glass material. However, in this study, the absorption value obtained is still at the lower limit of the SNI standard.

The higher the density of lightweight concrete, the higher its compressive strength; conversely, the lower the density of lightweight concrete, the higher its water absorption, which can cause a decrease in the concrete's strength. In this research, the concrete produced with a 20% *fly ash* mixture has the best performance. In terms of density values, both the 21-day-old and 28-day-old concretes followed the quality of category A lightweight concrete. As for water absorption, the best value is owned by the concrete mixture with 20% *fly* ash content, although it does not meet the expected value. However, when compared to concrete samples that do not contain *fly ash*, it is known that the test results on concrete samples without *fly ash* (0%) have higher compressive strength and density values, and the percentage of water absorption is following SNI standards. These results suggest that fly ash is not recommended for use in concrete mixes. The lightweight, *porous*, and high-boiling-point nature of *fly ash* indicates that it does not blend well into the concrete mix. This is supported by *trial-and-error* testing, where the determination of a small w/c ratio causes the sample not to adhere tightly. When more water is added (tried on several variations of w/c ratio, ranging from 0.30 to 0.95), it cannot produce a good sample.

CONCLUSIONS

The best performance of concrete was achieved with a 20% fly ash admixture. Based on the storage time of the concrete, the 28-day-old concrete with a 20% fly ash admixture performed better than the 21-day-old concrete, and both met the criteria for quality A concrete in terms of density values while meeting the requirements for quality C in terms of compressive strength values. While the absorbency of lightweight concrete is at the lower limit of the SNI standard for 0%-40% fly ash mixture percentages, the value is significantly different for concrete with a 60% fly ash amount.

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